ASR Cloud Life Cycle Focus Group White Paper: Measurement and Modeling of Ice Physical and Radiative Properties

Background

The Intergovernmental Panel on Climate Change (IPCC, 2007) has identified the response of clouds to climate change as the major source of uncertainty in predicting future climate change scenarios. Many processes that govern the evolution of clouds in models having a variety of temporal and spatial scales occur on scales smaller than model grid boxes, yet simulations are sensitive to the manner in which subgrid-scale processes are represented. In order to adequately represent how the radiative impact of clouds responds to changing environmental conditions in such models, it is necessary to quantify what controls the physical and radiative properties of clouds.

Solid crystals in ice-phase and mixed-phase clouds exert a strong impact on the Earth's radiative budget by reflecting incoming solar radiation back to space (cloud albedo effect), by absorbing and emitting longwave radiation (greenhouse effect), and by influencing the radiatively important liquid phase. The key to understanding and predicting the microphysical and radiative properties of ice clouds, which control their radiative influence, lies in characterizing the physical properties upon which they rest. Prior in-situ, laboratory and remote sensing studies have acquired a large database on the properties of ice clouds (total ice water content IWC, total particle concentration Ni, total extinction and particle size distributions PSDs), but with varying degrees of accuracy that have not been well quantified. Therefore it is not well known how these properties vary according to geographic location, cloud type, cloud formation mechanism and other dynamical and meteorological factors. Such knowledge is needed in order to develop a process-oriented understanding of the microphysical and dynamical processes occurring in ice clouds and hence to develop accurate parameterizations for large-scale, mesoscale and large eddy simulation models. Thus, additional data describing ice clouds are needed in a variety of conditions. A full range of ground-based remote sensing, space-based remote sensing and in-situ measurements are required to fulfill this need because each offers advantages in terms of spatial coverage (satellite), temporal resolution (ground-based remote sensing), or detailed view of ice crystals (in-situ). However, bringing these disparate data sources together with the treatment of ice in current cloud and climate models requires advances in our understanding of the physical and radiative properties of individual ice crystals and of ice crystal populations globally.

A physically-based representation of the microphysical and radiative properties of ice clouds is especially needed. Ice crystals have varying shapes and sizes that are not spherical. But, many models still represent ice particles as spheres when describing microphysical growth processes, which leads to errors when describing ice growth processes that determine the height or time evolution of the PSD (Mitchell 1988). In models that do consider non-spherical particles, area- and mass-dimensional power laws arecommonly used in the modeling of cloud microphysics and optics. However, the adequacy of such relationships to describe a wide range of microphysical processes (such as sedimentation, riming, aggregation, and break-up, or the effect of deposition/sublimation on particle shape), in addition to the radiative properties of particle populations, remains poorly known. Particle properties are known to be functions of temperature, relative humidity, riming/sublimation/deposition history, and perhaps ice nucleation substrate, resulting in a plethora of individual ice crystal properties. The importance of diversity within individual crystal populations to microphysics and radiatiion is poorly established. Further, the observations upon which standard area- and mass-dimensional relationships are based are subject to uncertainty, and hence the coefficients that describe the power laws can be selected from a surface of equally realizable solutions in the coefficient phase space (e.g., McFarquhar et al. 2003). For this reason probability distribution functions of these relationships, related to temperature and other environmental parameters, may be useful for cloud modeling.

The absorption and extinction optical properties of ice clouds can be described in terms of ice particle projected areas and masses, the ice PSD, and perhaps the shape model that is used to characterize the ice crystals. Earlier work used spheres and Mie theory to characterize the optical properties, but climate models (e.g. CESM1) have now begun to employ ice optics predicted from ice particle A-D and m-D power laws. Moreover, satellite and ground-based remote sensing retrievals of ice cloud properties depend strongly on these power laws and also on particle shapes/habits which influence scattering properties. In summary, by beginning with the fundamentals of ice particle area, mass, the ice PSD, and the natural diversity of particle habits, ice particle growth/sublimation processes, fall velocities and optical properties can theoretically be calculated and experimentally confirmed. The influence of uncertainties on process rates in models can also be estimated. The overarching goal of this focus group is to thus to develop a unified probability-based approach complete with uncertainty analysis for characterizing ice cloud physical and radiative properties and processes in models with a variety of temporal and spatial scales. By focusing on these fundamentals, these processes/optical properties/retrievals can be improved in an integrated, internally consistent and unified manner.

Activities

The activities of this focus group are diverse but all are related to improving the representation of ice particle properties in climate models. Some planned activities are:

1) IOP data: extend analysis of existing single-particle data (e.g. in situ probe measurements from SPARTICUS, ISDAC, TWP-ICE, M-PACE, etc.) to characterize the probability distribution of ice particle properties in terms of temperature, cloud type, geographical location, evolution stage and riming and reduce uncertainties thereof.

2) Identify gaps in geographical locations and meteorological conditions where additional in-situ data are needed to characterize the ice crystal properties.

3) Develop a general analytical framework for ice particle properties considering environmental conditions such as temperature and the degree of riming.

4) Identify a common ice particle property framework suitable for all model types, including a treatment of uncertainty regarding ice particle properties and derived quantities.

5) Develop a unified description of the microphysical and radiative properties of ice particles.

6) Determine how well the microphysical and radiative properties of ice clouds need to be known in order to obtain accurate estimates of cloud radiative forcing (e.g., maybe within 5% which is commonly stated as the goal).

7) Improve the representation of effective ice particle size and fall-speed in GCMs, noting both depend on the area and mass of ice particles.

8) Understand and model the dependence of ice particle properties and the ice PSD on homogeneous and heterogeneous ice nucleation processes.

9) Using the new ARM 2D video disdrometers at Barrow this winter (Oct 1 - May 2012), characterize ice crystal aggregates for modeling radar measurements and microphysical processes.

10) Develop techniques to infer ice particle habits, their orientation and other shape parameters from scanning polarimetric ARM radars.

11) Conduct radiation closure experiments using satellite remote sensing and collocated in situ measurements to evaluate ice particle properties for models and retrieval algorithms.

We will develop a strategy for filling in these knowledge gaps through dedicated field campaigns and subsequent analysis, laboratory studies, and theoretical/modeling studies. We will assist other focus groups and ASR PIs in achieving their goals through sharing progress in characterizing ice particle properties, ice microphysics and optics, and remote sensing.

Participants

Researchers interested in participating in this group include Ann Fridlind, Yanluan Lin, David Mitchell, Greg McFarquhar, Hans Verlinde, Giovanni Botta, Subhashree Mishra and Sergey Matrosov. David Mitchell and Greg McFarquhar are willing to lead.

Metric

To the best of our knowledge, no metric has yet been developed for characterizing how well ice crystal properties must be known. Our group will attempt to identify how well the physical properties (e.g., PSDs and fall speeds in terms of maximum dimension or particle mass; shape features influencing susceptibility to riming, aggregation, break-up or multiplication) and optical properties (e.g., aspect ratios, asymmetry parameter, and absorption and extinction coefficients) need to be known and then develop suitable parameterizations for models that fulfill established goals.

References

McFarquhar, G.M., S. Iacobellis, and R.C.J. Somerville, 2003: SCM simulations of tropical ice clouds using observationally based parameterizations of microphysics. J. Climate, 11, 1643-1664.

Mitchell, D.L., 1988: Evolution of snow-size spectra in cyclonic storms. I: Snow growth by vapor deposition and aggregation. *J. Atmos. Sci.*, **45**, 3431-3451.